BRL-MR-3728

DTIC FILE COPY

MEMORANDUM REPORT BRL-MR-3728

BRL

1938 – Serving the Army for Fifty Years – 1988

AD-A203 767

DENSITY OF TRIETHANOLAMMONIUM NITRATE AND LIQUID PROPELLANT

RONALD A. SASSÉ

DECEMBER 1988

APPROVED FOR PUBLIC RELEASE; DISTRIBUTION UNLIMITED.

U.S. ARMY LABORATORY COMMAND

BALLISTIC RESEARCH LABORATORY

ABERDEEN PROVING GROUND, MARYLAND

DESTRUCTION NOTICE

Destroy this report when it is no longer needed. DO NOT return it to the originator.

Additional copies of this report may be obtained from the National Technical Information Service, U.S. Department of Commerce, Springfield, VA 22161.

The findings of this report are not to be construed as an official Department of the Army position, unless so designated by other authorized documents.

The use of trade names or manufacturers' names in this report does not constitute indorsement of any commercial product.

UNCLASSIFIED

SECURITY CLASSIFICATION OF THIS PAGE

REPORT DOCUMENTATION PAGE

Form Approved OMB No. 0704-0188

1a. REPORT SECURITY CLASSIFICATION Unclassified	1b. RESTRICTIVE MARKINGS
2a. SECURITY CLASSIFICATION AUTHORITY	3. DISTRIBUTION/AVAILABILITY OF REPORT APPROVED FOR PUBLIC RELEASE; DISTRIBUTION UNLIMITED.
2b. DECLASSIFICATION/DOWNGRADING SCHEDULE	
4. PERFORMING ORGANIZATION REPORT NUMBER(S) BRL-MR-3728	5. MONITORING ORGANIZATION REPORT NUMBER(S)
6a. NAME OF PERFORMING ORGANIZATION US Army Ballistic Research Laboratory 6b. OFFICE SYMBOL (If applicable) SLCBR-IB	7a. NAME OF MONITORING ORGANIZATION
6c. ADDRESS (City, State, and ZIP Code) Aberdeen Proving Ground, MD 21005-5066	7b. ADDRESS (City, State, and ZIP Code)
8a. NAME OF FUNDING/SPONSORING ORGANIZATION 8b. OFFICE SYMBOL (If applicable)	9. PROCUREMENT INSTRUMENT IDENTIFICATION NUMBER
8c. ADDRESS (City, State, and ZIP Code)	10. SOURCE OF FUNDING NUMBERS PROGRAM ELEMENT NO. 61102A PROJECT NO. AH43 TASK NO. WORK UNIT ACCESSION NO.

11. TITLE (Include Security Classification)

DENSITY OF TRIETHANOLAMMONIUM NITRATE AND LIQUID PROPELLANT

12. PERSONAL AUTHOR(S)

Ronald A. Sasse'

13a. TYPE OF REPORT	13b. TIME COVERED	14. DATE OF REPORT (Year, Month, Day)	15. PAGE COUNT
Final	FROM Mar 88 TO Sep 88		

16. SUPPLEMENTARY NOTATION

This report is adjunct to BRL-MR-3720, December 1988.

17. COSATI CODES

FIELD	GROUP	SUB-GROUP
19	01	
21	02	

18. SUBJECT TERMS (Continue on reverse if necessary and identify by block number)

Hydroxylammonium Nitrate, Triethanolammonium Nitrate, HAN, TEAN, 1845, 1846, Density, Liquid Propellant, LPG, LP

19. ABSTRACT (Continue on reverse if necessary and identify by block number)

The density of hydroxylammonium nitrate based liquid propellants has been evaluated with particular attention given to the system 1845 containing triethanolammonium nitrate as fuel. It was found that density relationships of such systems could be correlated to the molten density of ingredients as opposed to crystalline density values. Equations are presented relating densities to concentrations and satisfactory comparisons are made to experimental measurements. Keywords: Liquid Gun propellants.(

20. DISTRIBUTION/AVAILABILITY OF ABSTRACT ☐ UNCLASSIFIED/UNLIMITED ☒ SAME AS RPT. ☐ DTIC USERS	21. ABSTRACT SECURITY CLASSIFICATION Unclassified
22a. NAME OF RESPONSIBLE INDIVIDUAL MR. RONALD A. SASSE'	22b. TELEPHONE (Include Area Code) 301-278-6172 22c. OFFICE SYMBOL SLCBR-IB-I

DD Form 1473, JUN 86 Previous editions are obsolete.

SECURITY CLASSIFICATION OF THIS PAGE

UNCLASSIFIED

TABLE OF CONTENTS

I. INTRODUCTION

For several reasons, this author was convinced that it would be both proper and expedient to present an evaluation of the densities of liquid propellant solutions in two parts using the natural divisions of oxidizer and fuel. This approach offers the advantage of following the modes of preparation where the constituents are first prepared as separate solutions which are then mixed to make propellant. This division also afforded the opportunity to bring to print, at an early time, some practical data on the solution characteristics of the oxidizer hydroxylammonium nitrate (HAN) and allowed an extended time period to administratively release data pertaining to the fuel triethanolammonium nitrate (TEAN). In addition, the delay allowed new experiments to be performed and new ideas evaluated.

II. BACKGROUND

Eli Freedman (BRL-Emeritus) as early as 1981 had considered HAN-based propellants as a mixture of ingredients having linear additive properties and he offered generalized equations relating individual component densities and their respective concentrations to propellant densities.[1] Such predictions were useful, at that time, for estimating some thermodynamic quantities and also gave some anticipated solution densities. In fact, at the start of writing this paper his value of 1.20 g/cm^3 for the density of TEAN was the only value available. He recently sparked further interest in this subject by asking if recent work by Sasse', et al.,[2] could render better estimates of propellant density. This paper attempts to answer that question affirmatively.

It was recently reported[2] that the functional relationship between HAN concentration and density is represented by a second order equation that, when extrapolated to pure HAN, intersects the density of melted anhydrous HAN as opposed to the crystalline density value. The following regression equation was derived from several HAN solutions at 20°C, where concentration has units of moles/liter and density has units of g/cm^3:

$$\rho_{HAN} = 0.9935 + 0.046630\ M - 0.00040\ M^2 \qquad (1)$$

The kernel of the present approach is to assume the above equation embraces both the non-linear ion-solute and ion-ion interactions and linearly add to this second order function the density/volume/concentration characteristics of various fuels such as TEAN which is used in the liquid propellants 1845 and 1846. Results of these approximations will be compared to experimentally derived density measurements for the propellant 1845.

III. DISCUSSION

To undertake this calculation the densities of several TEAN solutions are required to form a data base much like the one previously used for determining HAN-solution relationships. Fortunately, Gail Stein,[3] of the Naval Ordnance Station, made such measurements using four temperatures (21, 34, 53 and 69°C) and presented density and viscosity data for three fuels (TEAN, diethanolammonium nitrate and monoethanolammonium nitrate). Table 1 gives her values for the density of TEAN solutions at 21°C.

Table 1. Density of TEAN Solutions

Percent by Weight	Concentration moles/liter	Density g/cm^3
20	0.9952	1.056
40	2.1149	1.122
60	3.3618	1.189
70	4.0375	1.224
80	4.7613	1.263
100*	6.2580*	1.328*
100	6.0789	1.29**
100	6.7857	1.44***

----

* Extrapolated from solution values
** Anhydrous melt
*** Crystalline value

These data were fitted to two linear regression lines, one in units of weight percent and the other in units of moles, M.

$$\rho_{TEAN} = 0.985896 + 0.003424\ (\mathrm{wt.\%}) \qquad (2)$$

or,

$$\rho_{TEAN} = 1.003784 + 0.0546873\ M \qquad (3)$$

Excessive digits are given for the coefficients to prevent successive round off errors but obviously the constants are not known to better than one part in a thousand. The extrapolated density at 100% TEAN is 1.328 g/cm^3. In contrast, six values for the density of crystalline TEAN gave an average of 1.44 ± 0.01 g/cm^3 as measured by Warren Hillstrom of the BRL using a Micromertics automatic helium pycnometer. This sharp difference between the crystalline and extrapolated solution density values for TEAN parallels a similar relationship found for the HAN system.[2]

To complete the relationships, the density of a liquid melt of TEAN was determined to be 1.29 g/cm^3 which of necessity had to be obtained above the melting point of TEAN at a temperature of about 90°C. At this temperature the melt has expanded and does not truly represent just the breaking of crystalline bonds at 20°C. Of the two values of 1.29 and 1.328, the later estimate was selected to better represent solution properties of TEAN and will be used in the calculations that follow. Lastly, the chemical composition of the propellant is required and the "ideal" formulation for propellant 1845 is given in Table 2.

Table 2. The Ideal Chemical Composition of 1845

Species	Composition weight %	Composition moles/liter
HAN	63.23	9.62
TEAN	19.96	1.38
H_2O	16.81	13.64

IV. CALCULATIONS

In order to separate the constitutive effects of TEAN and HAN solutions, a liter of propellant is considered, consisting of two parts: one of pure TEAN and the other part a solution of HAN. These volume elements are noted as V_{TEAN} and V_{HAN-H_2O}.

To estimate the concentration of HAN in this idealized division, the volume of TEAN is subtracted from the propellant volume. Equations (3), (4), and (5) are offered to achieve this result. From the relationship:

$$M_1V_1 = M_2V_2 \tag{4}$$

where M_1V_1 represents HAN in the propellant and M_2V_2 represents HAN in its sub-divided volume element.

Expansion first yields,

$$M_1V_1 = M_2 \left[V_1 - V_{TEAN}\right] \tag{5}$$

and further expansion yields,

$$M_1V_1 = M_2 \left[V_1 - \frac{M_{TEAN}(MW_{TEAN})}{\rho_{TEAN}}\right] \tag{6}$$

where M_{TEAN} is the number of moles of TEAN in a liter of propellant or 1.38 moles/liter and MW is the molecular weight of TEAN (212.21).

Substitution gives:

$$9.62\ (1000) = M_2 \left[1000 - \frac{1.38\ (212.21)}{1.328}\right] \tag{7}$$

Thus the concentration of HAN in the divided system is M_2 or 12.34 moles/liter, and it has a volume of V_1-V_{TEAN} or 779.48 cm^3.

The density of HAN at this concentration is given by applying the second order equation 1 and is 1.5080. The density of propellant $\rho_{1,2}$ is then assumed to be the weighted average of its constituents or:

$$\rho_{1,2}\ V_{1,2} = \rho_1V_1 + \rho_2V_2 \tag{8}$$

expansion yields

$$\rho_{1845} = \rho_{HAN-H_2O} \left[\frac{V_{HAN-H_2O}}{V_{1,2}}\right] + \rho_{TEAN} \left[\frac{V_{TEAN}}{V_{1,2}}\right]. \tag{9}$$

and substitution yields

$$\rho_{1845} = 1.5080 \left[\frac{779.48}{1000}\right] + 1.328 \left[\frac{1000-779.48}{1000}\right] \tag{10}$$

and thus the density of 1845 is calculated to be 1.4676 g/cm^3. Propellant 1846 is slightly more dilute than 1845; thus, incorporating the chemical composition of 1846 into the equations offered would cha.acterize that systems density.

Messina, et al.,[4] offered an equation relating the density of 1845 (lot 244) to temperature, T in degrees centigrade, based on data obtained at 5, 25, 45, and 65 degrees. The equation offered was:

$$\rho_{1845} = 1.4695 - 7.1188 \times 10^{-4}\ (T) \tag{11}$$

which at 20 degrees yields a value of 1.4688 g/cm^3. The agreement between this value and the value obtained using Eqs. (4) through (10) gives a result that is better than the number of significant figures used to express concentration. Another equation was offered[5] that differed from Eq. (11) by about one percent; however, that equation was the result of experiments conducted at but two temperatures and the experimenters used a laboratory prepared sample that was not as documented as lot 224. Thus, that equation is not considered the equation of merit.[6]

A simpler calculation predicting the density of propellant can be accomplished by mixing two properly constituted solutions of HAN and TEAN. Once the concentration of one constituent is chosen, within the boundary conditions of the respective crystalline densities, then all required sub-quantities can be calculated. The various inter-relationships are shown by Figure 1 where a line normal to the volume axis cuts the two curves giving the volume and normality of HAN and TEAN required to make a liter of the propellant 1845. For example, an arbitrary line was drawn through the 700 ml HAN and 300 ml TEAN values that also intersected concentrations of 13.7429 m/l and 4.6000 m/l; the required concentrations for HAN and TEAN. Respected densities were given by Eqs. (1) and (3) and a final propellant density of 1.46775 g/cm^3 was obtained by employing the weight averaging Eq. (8). This density value agrees with the experimentally measured value and also with the value obtained earlier using Eqs. (4) through (10).

V. CONCLUSION

From the equations and corresponding arguments presented, the density of the system HAN, TEAN and water can be calculated from their respective concentrations. Further, the density of either HAN or TEAN solutions, considered individually, can be also be estimated from their respective concentrations. This may be of benefit to those that concentrate such materials. Such relationships may be of help in the general art of formulation but clearly final concentrations will be established by chemical analysis and not by density.

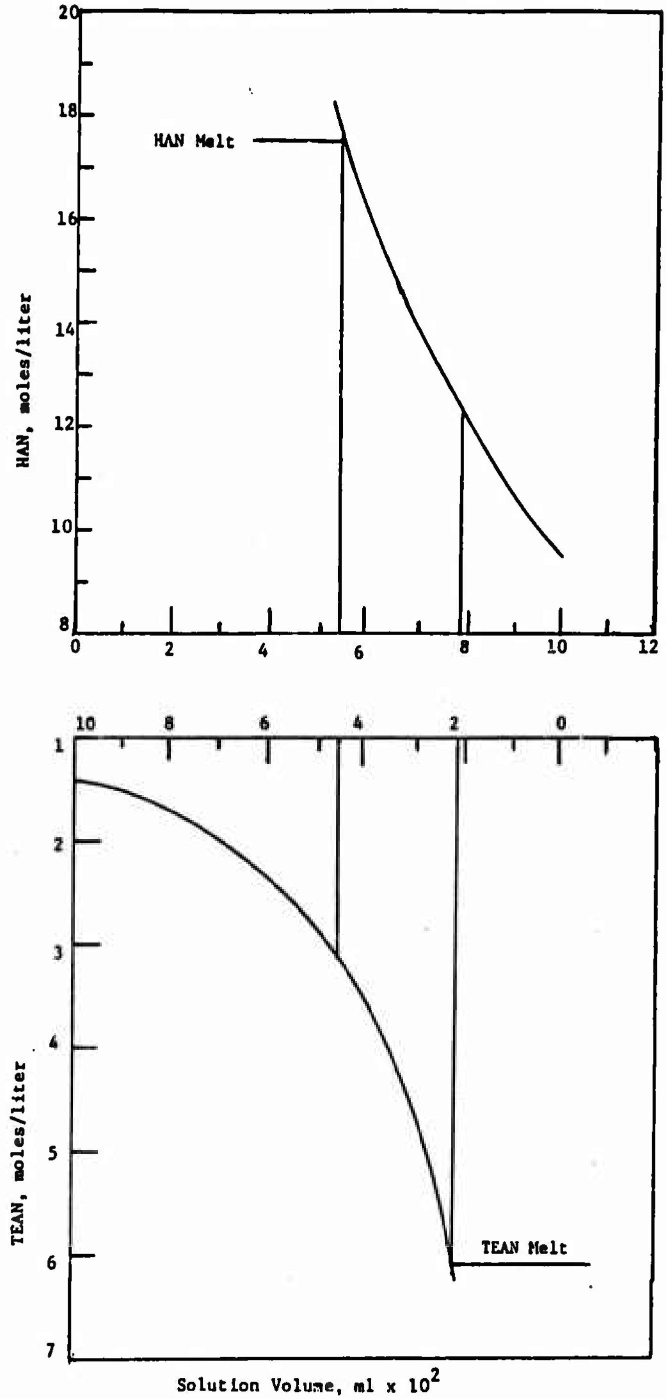

Figure 1. Mixing Solutions of Various Concentrations of HAN and TEAN to Make Propellant 1845

REFERENCES

1. E. Freedman and K.E. Travis, "Composition, Nomenclature, Densities and Computer Impetuses of Aqueous Liquid Gun Propellants" (U), CONFIDENTIAL BRL Report No. MR-03076, US Army Ballistic Research Laboratory, Aberdeen Proving Ground, MD, February 1981.

2. R.A. Sasse', M.A. Davies, R.A. Fifer, M.M. Decker, and A.J. Kotlar, "Density Of Hydroxylammonium Nitrate Solutions," BRL Report No. MR-3720, US Army Ballistic Research Laboratory, Aberdeen Proving Ground, MD, December 1988.

3. G. Stein, "Viscosity Data on TEAN Solutions," U.S. Government Agencies Only: Indian Head Technical Note 001, Naval Ordnance Station, Indian Head MD, June 1986.

4. N.A. Messina, H.H. Tseng, L.S. Ingram, and M. Summerfeild, "The Role of Physical Properties in Dynamic Loading Processes and Bubble Collapse of Liquid Monopropellants for LPG Application," Proceedings of the 21st JANNAF Combustion Meeting, CPIA Publication 412, Vol. II, p. 515, October 1984.

5. N. Klein, M.M. Decker, E. Freedman, C.S. Leveritt, J.Q. Wojciechowski, C.A. Spiegel, and N.A. Messina, "Effect of Molecular Structure on the Viscosity of Liquid Propellants," Proceedings of the 23rd JANNAF Combustion Meeting, CPIA Publication 457, Vol. III, p. 185, October 1986.

6. N.A. Messina, Princeton Combustion Research Laboratories, NJ, Private Communication 1988.

DISTRIBUTION LIST

No. Of Copies	Organization
12	Administrator Defense Technical Info Center ATTN: DTIC-DDA Cameron Station Alexandria, VA 22304-6145
1	HQ DA (SARD-TR) Washington, DC 20310-0001
1	Commander US Army Materiel Command ATTN: AMCDRA-ST 5001 Eisenhower Avenue Alexandria, VA 22333-0001
1	Commander US Army Laboratory Command ATTN: AMSLC-DL Adelphi, MD 20783-1145
2	Commander Armament R&D Center US Army AMCCOM ATTN: SMCAR-MSI Pictinny Arsenal, NJ 07806-5000
2	Commander Armament R&D Center US Army AMCCOM ATTN: SMCAR-TDC Picatinny Arsenal, NJ 07806-5000
1	Director Benet Weapons Laboratory Armament RD&E Center US Army AMCCOM ATTN: SMCAR-LCB-TL Watervliet, NY 12189-4050
1	Commander US Army Armament, Munitions and Chemical Command ATTN: SMCAR-ESP-L Rock Island, IL 61299-5000
1	Commander US Army Aviation Systems Command ATTN: AMSAV-DACL 4300 Goodfellow Blvd. St. Louis, MO 63120-1798
1	Director US Army Aviation Research and Technology Activity Ames Research Center Moffett Field, CA 94035-1099
4	Commander US Army Research Office ATTN: R. Ghirardelli D. Mann R. Singleton R. Shaw P.O. Box 12211 Research Triangle Park, NC 27709-2211
1	Commander US Army Communications - Electronics Command ATTN: AMSEL-ED Fort Monmouth, NJ 07703-5022
2	Commander Armament R&D Center US Army AMCCOM ATTN: SMCAR-LCA-G, D.S. Downs J.A. Lannon Dover, NJ 07801
1	Commander Armament R&D Center US Army AMCCOM ATTN: SMCAR-LC-G, L. Harris Dover, NJ 07801

DISTRIBUTION LIST

No. Of Copies	Organization
1	Commander Armament R&D Center US Army AMCCOM ATTN: SMCAR-SCA-T, L. Stiefel Dover, NJ 07801
2	Commander US Army Missile Command ATTN: AMSMI-RD AMSMI-AS Redstone Arsenal, AL 35898-5000
2	Commander US Army Missile Command ATTN: AMSMI-RK, D.J. Ifshin W. Wharton Redstone Arsenal, AL 35898
1	Commander US Army Missile Command ATTN: AMSMI-RKA, A.R. Maykut Redstone Arsenal, AL 35898-5249
1	Commander US Army Tank Automotive Cmd ATTN: AMSTA-DI Warren, MI 48397-5000
1	Director US Army TRADOC Analysis Cmd ATTN: ATAA-SL White Sands Missile Range, NM 88002-5502
1	Commandant US Army Infantry School ATTN: ATSH-CD Fort Benning, GA 31905-5660
1	Commander US Army Development and Employment Agency ATTN: MODE-ORO Fort Lewis, WA 98433-5000

No. Of Copies	Organization
1	Office of Naval Research Department of the Navy ATTN: R.S. Miller, Code 432 800 N. Quincy Street Arlington, VA 22217
1	Commander Naval Air Systems Command ATTN: J. Ramnarace, AIR-54111C Washington, DC 20360
2	Commander Naval Ordnance Station ATTN: C. Irish P.L. Stang, Code 515 Indian Head, MD 20640
1	Commander Naval Surface Weapons Center ATTN: J.L. East, Jr., G-23 Dahlgren, VA 22448-5000
2	Commander Naval Surface Weapons Center ATTN: R. Bernecker, R-13 G.B. Wilmot, R-16 Silver Spring, MD 20902-5000
5	Commander Naval Research Laboratory ATTN: M.C. Lin J. McDonald E. Oran J. Shnur R.J. Doyle, Code 6110 Washington, DC 20375
1	Commanding Officer Naval Underwater Systems Center Weapons Dept. ATTN: R.S. Lazar/Code 36301 Newport, RI 02840
1	Superintendent Naval Postgraduate School Dept. of Aeronautics ATTN: D.W. Netzer Monterey, CA 93940

DISTRIBUTION LIST

No. Of Copies	Organization
4	AFRPL/DY, Stop 24 ATTN: R. Corley R. Geisler J. Levine D. Weaver Edwards AFB, CA 93523-5000
1	AFRPL/MKPB, Stop 24 ATTN: B. Goshgarian Edwards AFB, CA 93523-5000
1	AFOSR ATTN: J.M. Tishkoff Bolling Air Force Base Washington, DC 20332
1	Air Force Armament Laboratory ATTN: AFATL/DLODL Eglin AFB, FL 32542-5000
1	AFWL/SUL Kirtland AFB, NM 87117-5800
1	NASA Langley Research Center Langley Station ATTN: G.B. Northam/MS 168 Hampton, VA 23365
4	National Bureau of Standards ATTN: J. Hastie M. Jacox T. Kashiwagi H. Semerjian US Department of Commerce Washington, DC 20234
1	OSD/SDIO/UST ATTN: L.H. Caveny Pentagon Washington, DC 20301-7100
1	Aerojet Solid Propulsion Co. ATTN: P. Micheli Sacramento, CA 95813
1	Applied Combustion Technology, Inc. ATTN: A.M. Varney P.O. Box 17885 Orlando, FL 32860
2	Applied Mechanics Reviews The American Society of Mechanical Engineers ATTN: R.E. White A.B. Wenzel 345 E. 47th Street New York, NY 10017
1	Atlantic Research Corp. ATTN: M.K. King 5390 Cherokee Avenue Alexandria, VA 22314
1	Atlantic Research Corp. ATTN: R.H.W. Waesche 7511 Wellington Road Gainesville, VA 22065
1	AVCO Everett Rsch. Lab. Div. ATTN: D. Stickler 2385 Revere Beach Parkway Everett, MA 02149
1	Battelle Memorial Institute Tactical Technology Center ATTN: J. Huggins 505 King Avenue Columbus, OH 43201
1	Cohen Professional Services ATTN: N.S. Cohen 141 Channing Street Redlands, CA 92373
1	Exxon Research & Eng. Co. ATTN: A. Dean Route 22E Annandale, NJ 08801

DISTRIBUTION LIST

No. Of Copies	Organization
1	Ford Aerospace and Communications Corp. DIVAD Division Div. Hq., Irvine ATTN: D. Williams Main Street & Ford Road Newport Beach, CA 92663
1	General Applied Science Laboratories, Inc. 77 Raynor Avenue Ronkonkama, NY 11779-6649
1	General Electric Armament & Electrical Systems ATTN: M.J. Bulman Lakeside Avenue Burlington, VT 05401
1	General Electric Company 2352 Jade Lane Schenectady, NY 12309
1	General Electric Ordnance Systems ATTN: J. Mandzy 100 Plastics Avenue Pittsfield, MA 01203
2	General Motors Rsch Labs Physics Department ATTN: T. Sloan R. Teets Warren, MI 48090
2	Hercules, Inc. Allegany Ballistics Lab. ATTN: R.R. Miller E.A. Yount P.O. Box 210 Cumberland, MD 21501
1	Hercules, Inc. Bacchus Works ATTN: K.P. McCarty P.O. Box 98 Magna, UT 84044

No. Of Copies	Organization
1	Honeywell, Inc. Government and Aerospace Products ATTN: D.E. Broden/ MS MN50-2000 600 2nd Street NE Hopkins, MN 55343
1	IBM Corporation ATTN: A.C. Tam Research Division 5600 Cottle Road San Jose, CA 95193
1	IIT Research Institute ATTN: R.F. Remaly 10 West 35th Street Chicago, IL 60616
2	Director Lawrence Livermore National Laboratory ATTN: C. Westbrook M. Costantino P.O. Box 808 Livermore, CA 94550
1	Lockheed Missiles & Space Co. ATTN: George Lo 3251 Hanover Street Dept. 52-35/B204/2 Palo Alto, CA 94304
1	Los Alamos National Lab ATTN: B. Nichols T7, MS-B284 P.O. Box 1663 Los Alamos, NM 87545
1	National Science Foundation ATTN: A.B. Harvey Washington, DC 20550
1	Olin Corporation Smokeless Powder Operations ATTN: V. McDonald P.O. Box 222 St. Marks, FL 32355

DISTRIBUTION LIST

No. Of Copies	Organization
1	Paul Gough Associates, Inc. ATTN: P.S. Gough 1048 South Street Portsmouth, NH 03801
2	Princeton Combustion Research Laboratories, Inc. ATTN: M. Summerfield N.A. Messina 475 US Highway One Monmouth Junction, NJ 08852
1	Hughes Aircraft Company ATTN: T.E. Ward 8433 Fallbrook Avenue Canoga Park, CA 91303
1	Rockwell International Corp. Rocketdyne Division ATTN: J.E. Flanagan/HB02 6633 Canoga Avenue Canoga Park, CA 91304
4	Sandia National Laboratories Combustion Sciences Dept. ATTN: R. Cattolica S. Johnston P. Mattern D. Stephenson Livermore, CA 94550
1	Science Applications, Inc. ATTN: R.B. Edelman 23146 Cumorah Crest Woodland Hills, CA 91364
1	Science Applications, Inc. ATTN: H.S. Pergament 1100 State Road, Bldg. N Princeton, NJ 08540
3	SRI International ATTN: G. Smith D. Crosley D. Golden 333 Ravenswood Avenue Menlo Park, CA 94025
1	Stevens Institute of Tech. Davidson Laboratory ATTN: R. McAlevy, III Hoboken, NJ 07030
1	Textron, Inc. Bell Aerospace Co. Division ATTN: T.M. Ferger P.O. Box 1 Buffalo, NY 14240
1	Thiokol Corporation Elkton Division ATTN: W.N. Brundige P.O. Box 241 Elkton, MD 21921
1	Thiokol Corporation Huntsville Division ATTN: R. Glick Huntsville, AL 35807
3	Thiokol Corporation Wasatch Division ATTN: S.J. Bennett P.O. Box 524 Brigham City, UT 84302
1	United Technologies ATTN: A.C. Eckbreth East Hartford, CT 06108
3	United Technologies Corp. Chemical Systems Division ATTN: R.S. Brown T.D. Myers (2 copies) P.O. Box 50015 San Jose, CA 95150-0015
1	Universal Propulsion Company ATTN: H.J. McSpadden Black Canyon Stage 1 Box 1140 Phoenix, AZ 85029

DISTRIBUTION LIST

No. Of Copies	Organization
1	Veritay Technology, Inc. ATTN: E.B. Fisher 4845 Millersport Highway P.O. Box 305 East Amherst, NY 14051-0305
1	Brigham Young University Dept. of Chemical Engineering ATTN: M.W. Beckstead Provo, UT 84601
1	California Institute of Tech. Jet Propulsion Laboratory ATTN: MS 125/159 4800 Oak Grove Drive Pasadena, CA 91103
1	California Institute of Technology ATTN: F.E.C. Culick/ MC 301-46 204 Karman Lab. Pasadena, CA 91125
1	University of California, Berkeley Mechanical Engineering Dept. ATTN: J. Daily Berkeley, CA 94720
1	University of California Los Alamos Scientific Lab. P.O. Box 1663, Mail Stop B216 Los Alamos, NM 87545
2	University of California, Santa Barbara Quantum Institute ATTN: K. Schofield M. Steinberg Santa Barbara, CA 93106
2	University of Southern California Dept. of Chemistry ATTN: S. Benson C. Wittig Los Angeles, CA 90007
1	Case Western Reserve Univ. Div. of Aerospace Sciences ATTN: J. Tien Cleveland, OH 44135
1	Cornell University Department of Chemistry ATTN: T.A. Cool Baker Laboratory Ithaca, NY 14853
1	Univ. of Dayton Rsch Inst. ATTN: D. Campbell AFRPL/PAP Stop 24 Edwards AFB, CA 93523
1	University of Florida Dept. of Chemistry ATTN: J. Winefordner Gainesville, FL 32611
3	Georgia Institute of Technology School of Aerospace Engineering ATTN: E. Price W.C. Strahle B.T. Zinn Atlanta, GA 30332
1	University of Illinois Dept. of Mech. Eng. ATTN: H. Krier 144MEB, 1206 W. Green St. Urbana, IL 61801
1	Johns Hopkins University/APL Chemical Propulsion Information Agency ATTN: T.W. Christian Johns Hopkins Road Laurel, MD 20707
1	University of Michigan Gas Dynamics Lab Aerospace Engineering Bldg. ATTN: G.M. Faeth Ann Arbor, MI 48109-2140

DISTRIBUTION LIST

No. Of Copies	Organization
1	University of Minnesota Dept. of Mechanical Engineering ATTN: E. Fletcher Minneapolis, MN 55455
3	Pennsylvania State University Applied Research Laboratory ATTN: K.K. Kuo H. Palmer M. Micci University Park, PA 16802
1	Pennsylvania State University Dept. of Mechanical Engineering ATTN: V. Yang University Park, PA 16802
1	Polytechnic Institute of NY Graduate Center ATTN: S. Lederman Route 110 Farmingdale, NY 11735
2	Princeton University Forrestal Campus Library ATTN: K. Brezinsky I. Glassman P.O. Box 710 Princeton, NJ 08540
1	Princeton University MAE Dept. ATTN: F.A. Williams Princeton, NJ 08544
1	Purdue University School of Aeronautics and Astronautics ATTN: J.R. Osborn Grissom Hall West Lafayette, IN 47906
1	Purdue University Department of Chemistry ATTN: E. Grant West Lafayette, IN 47906
2	Purdue University School of Mechanical Engineering ATTN: N.M. Laurendeau S.N.B. Murthy TSPC Chaffee Hall West Lafayette, IN 47906
1	Rensselaer Polytechnic Inst. Dept. of Chemical Engineering ATTN: A. Fontijn Troy, NY 12181
1	Stanford University Dept. of Mechanical Engineering ATTN: R. Hanson Stanford, CA 94305
1	University of Texas Dept. of Chemistry ATTN: W. Gardiner Austin, TX 78712
1	University of Utah Dept. of Chemical Engineering ATTN: G. Flandro Salt Lake City, UT 84112
1	Virginia Polytechnic Institute and State University ATTN: J.A. Schetz Blacksburg, VA 24061
1	Commandant USAFAS ATTN: ATSF-TSM-CN Fort Sill, OK 73503-5600
1	F.J. Seiler Research Lab (AFSC) ATTN: S.A. Shakelford USAF Academy, CO 80840-6528
1	Olin Chemical ATTN: D. Cawlfield P.O. Box 248 Charleston, TN 37310

DISTRIBUTION LIST

No. Of Copies	Organization
3	Olin Chemical ATTN: J. A. Leistra (1 copy) R. Dotson (2 copies) 24 Science Park S. Winchester Avenue P. O. Box 30-9644 New Haven, CT 06511
1	University of Illinois at Chicago ATTN: S. Murad Dept. of Chemical Engr. Box 4348 Chicago, IL 60680
1	Johns Hopkins University ATTN: W. Koski Dept. of Chemistry Charles and 34th Streets Baltimore, MD 21218
1	Director Benet Weapons Laboratory Armament R&D Center US Army AMCCOM ATTN: J. Frankel Watervliet, NY 12189-4050
2	Morton Thiokol, Inc. Elkton Division ATTN: R. A. Biddle P. O. Box 241 Elkton, MD 21921-0241
2	Commander Naval Ordnance Station ATTN: C. Stein Indian Head, MD 20640-5000
1	Commander US Army Laboratory Command ATTN: AMSLC-DL Adelphi, MD 20783-1145
1	Dir, Combat Development ATTN: ATSH-CD Fort Benning, GA 31905-5660
1	Air Force Armament Laboratory ATTN: AFATL/DLODL Eglin AFB, FL 32542-5000
1	The Rand Corporation P. O. Box 2138 Santa Monica, CA 90401-2138

Aberdeen Proving Ground

Dir, USAMSAA
ATTN: AMXSY-D
AMXSY-MP, H. Cohen

Cdr, USATECOM
ATTN: AMSTE-TO-F

Cdr, CRDEC, AMCCOM
ATTN: SMCCR-RSP-A
SMCCR-MU
SMCCR-SPS-IL

USER EVALUATION SHEET/CHANGE OF ADDRESS

This laboratory undertakes a continuing effort to improve the quality of the reports it publishes. Your comments/answers below will aid us in our efforts.

1. Does this report satisfy a need? (Comment on purpose, related project, or other area of interest for which the report will be used.) ____________________

2. How, specifically, is the report being used? (Information source, design data, procedure, source of ideas, etc.) ____________________

3. Has the information in this report led to any quantitative savings as far as man-hours or dollars saved, operating costs avoided, or efficiencies achieved, etc? If so, please elaborate. ____________________

4. General Comments. What do you think should be changed to improve future reports? (Indicate changes to organization, technical content, format, etc.) ____________________

BRL Report Number ____________ Division Symbol ____________

Check here if desire to be removed from distribution list. ____

Check here for address change. ____

Current address: Organization ____________________
Address ____________________

--------------------FOLD AND TAPE CLOSED--------------------

Director
U.S. Army Ballistic Research Laboratory
ATTN: SLCBR-DD-T(NEI)
Aberdeen Proving Ground, MD 21005-5066

OFFICIAL BUSINESS
PENALTY FOR PRIVATE USE $300

NO POSTAGE NECESSARY IF MAILED IN THE UNITED STATES

BUSINESS REPLY LABEL
FIRST CLASS PERMIT NO. 12062 WASHINGTON D.C.

POSTAGE WILL BE PAID BY DEPARTMENT OF THE ARMY

Director
U.S. Army Ballistic Research Laboratory
ATTN: SLCBR-DD-T(NEI)
Aberdeen Proving Ground, MD 21005-9989

Director
U.S. Army Ballistic Research Laboratory
ATTN: SLCBR-DD-T(NEI)
Aberdeen Proving Ground, MD 21005-5066

\- PASTE LABEL HERE -